TITLE

LOW PRESSURE DROP DEEP ELECTRICALLY ENHANCED FILTER

CLAIM FOR PRIORITY

[0001] This application makes reference to, claims all benefits inuring under 35 U.S.C. §111(b) from, and incorporates herein my provisional patent application entitled *Low Pressure Drop Deep Electrically Enhanced Filter* earlier filed in the United States Patent and Trademark Office on the 12th day of July 2002 and there duly assigned Serial No. 60/395,322, my provisional patent application entitled *Low Pressure Drop Deep Electrically Enhanced Filter* earlier filed in the United States Patent and Trademark Office on the 10th day of February 2003 and there duly assigned Serial No. 60/437,140, my provisional patent application entitled *Low Pressure Drop Deep Electrically Enhanced Filter* earlier filed in the United States Patent and Trademark Office on the 25th day of April 2003 and there duly assigned Serial No. 60/465,277, and my patent application entitled *LOW PRESSURE DROP DEEP ELECTRICALLY ENHANCED FILTER* earlier filed in the United States Patent & Trademark Office on 14 July 2003 and there duly assigned Serial No. 10/618,457.

BACKGROUND OF THE INVENTION

Technical Field

[0002] This application pertains to filters and filtration processes and systems generally and, more particularly, to the enablement of the use of deep filter media used in ionizing electrically enhanced filtration processes and filters while functioning as high performance devices with ultra-low pressure drop, to filtration systems and to processes or constructing filters and filtration systems.

Related Art

[0003] Jaisinghani, *A Safe Ionizing Field Electronically Enhanced Filter and Process For Safely Ionizing A Field Of An Electrically Enhanced Filter* U.S. Patent No. 5,403,383, describes an ionizing electrically enhanced filter that has sufficiently high performance to have become the only successfully commercialized Electrically Enhanced Filter (*i.e.*, EEF). It has found uses in cleanrooms and in other critical applications, and also in residential and commercial building applications requiring clean indoor air. Recently, *Consumer Reports*

(Feb 2003) rated a device based on the teachings of this patent as being the highest performance residential air cleaner.

[0004] The main advantages of electrically enhanced filtration technology are high filtration efficiency with low-pressure drop, higher filter dust holding capacity of life, and low resistance to air flow, the safety of these devices constructed with electrically enhanced technology and the ability of these devices to function without problems for the duration of the life of the product; these filters also have some bactericidal properties.

[0005] In contrast, non-EEF type conventional mechanical filters exhibit a higher pressure drop. Embodiments constructed according to the principles of U.S. Patent No. 5,403,383 are limited as a practical matter, to relatively shallow filter media with peak-to-peak depths of about six inches.

[0006] Recent advances in filter construction have resulted in the availability of very low-pressure drop mechanical filters. For example, a class of filters known as mini-pleated V-pack filters have lower pressure drop than older deep filters such as aluminum separator type folded media and other conventional filters. A typical V-pack filter is about twelve inches deep and has a filter efficiency of 99.99% with a particle size of 0.3 micrometers, and has a pressure drop of about one inch water column at a filter face flow velocity of 600 feet per minute. Another grade of such a V-pack filter has a filtration efficiency of 95% at 0.3 micrometers particle size, and has a pressure drop of about one-half of an inch water column (*i.e.*, 0.5" WC) at a filter face air flow velocity of 600 feet per minute. I have found that if such a 95% filter could be enhanced in a safe electrical manner to provide approximately 99.97 to 99.99% filtration efficiency at 0.3 micrometer particle size (commonly referred to as HEPA filtration efficiency), then an ultra low pressure drop HEPA filter could be achieved with significant savings in operational costs than are available with conventional HEPA filters. Similarly lower grade, deep V-pack or other forms of deep filter material could be safely electrically enhanced to produce higher efficiency filters having significantly lower pressure drops. The operating cost savings would be in terms of fan power required and the longevity of the filter, improvements that result in savings in terms of energy, downtime, labor and material costs related to filter replacement and maintenance. The consequential benefits in industrial applications (cf. Jaisinghani, "*Energy Efficient Cleanroom Design*", 2000) could be as high as 60% savings in energy consumption related to air moving.

[0007] Cheney and Spurgin in their *Electrostatically Enhanced HEPA Filter,* U.S. Patent

No. 4,781,736 describe an EEF that can be used with deeply folded filter media that has corrugated aluminum separators positioned within the folds. Cheney '736 is limited to using such separators as electrodes within folded dielectric filter media in paper form. The essential objective of Cheney '736 is an attempt to provide electrostatic augmented filtration that allows retrofitting or direct use of existing filters (referring to aluminum corrugated separator deep filters). Cheney '736 requires corrugated separators used as electrodes placed within folded media; if the electrodes in Cheney '736 were flat, those electrodes could not function as separators.

[0008] I have noticed that filters such as those taught by Cheney '736 rely upon sets of spacers to separate the filter media in an effort to reduce pressure drop and resistance to the air flow. I have found that this undesirably reduces the surface area of filter media available to remove particles from the air flow, principally due to the fact that these spacers have a minimum depth to the corrugations which restricts the number of pleats that can be used within an available volume. By contrast, mini pleat technology that uses glue beads or ribbons to separate the pleats enables approximately twice as much filter media when used in a V-pack configuration. Another problem that I have discovered, related to the use of aluminum separators, is that under fluctuating flow or start up flow conditions these sharp corrugated separators can cut the delicate fiber glass media used in such filters, causing damage and leakage within the filter media.

[0009] Embodiments of the Cheney and Spurgin disclosed in their U.S. Patent No. 4,781,736 reference are also restricted to the use of an ionizer that uses parallel plates because the flow is parallel to the air flow direction. I have noticed that there are problems with parallel ionizer plates attributable to dust particles of opposing charge that tend to accumulate on the ionizer plates because the dust particles have to travel only across the direction of the air flow in order to accumulate on the plates. As highly resistive dust builds up an accumulation on the plates, an opposing field can be created, thereby canceling the applied field strength that ionizes the air. I have observed that this phenomenon can sometimes generate undesired back corona discharge.

[0010] Cheney '736 also sought a significant reduction in the capacitance of the device in comparison to the teachings of Masuda found in U.S. Patent Nos. 4,357,150 and 4,509,958, in order to minimize the energy available for arcing. Although it is unclear whether this method may reduce the energy available for arcing as compared to Masuda '150 and '958, it

reduces neither arcing and the consequent damage to the media nor the potential for fire, because pin holes can be created on the delicate glass media even with low energy arcing. Embodiments of Masuda are highly prone to arcing.

[0011] I have also found that a device constructed in accordance with Cheney '763 lacks a uniform electrical field, exhibits a low collector field strength, demonstrates a high potential for sparking, tends to have excessive leakage current, and requires construction of its frame from non-conductive materials, as is explained in the following discussion.

[0012] In order to prevent sparking towards the frame material, the frame material in the practice of Cheney '736 must be a non-conductive material, typically wood, because the aluminum spacers of the upstream corrugated electrodes will probably contact the frame material at some location. Contemporary manufacturing methods have switched to the use of aluminum or metal channel frames that do not shed particles, provide better seals to the media and are not flammable. The use of organic materials for the frames as suggested by Cheney '736 is rather dirty, and thus undesirable for clean room applications.

[0013] It should be noted that Cheney '736 does not describe any values for electrode gaps or ranges of voltages used in any of the configurations illustrated, nor does Cheney '736 provide any results showing the efficacy of the embodiments disclosed. These practical difficulties and limitations upon performance are the main reason why a device such as taught by Cheney '736 has never been successfully commercialized. Additionally, aluminum separator folded filter type filter elements have become unpopular because this type of filter element tends to tear due to the sharp edges of the aluminum separators within the folded medium.

SUMMARY OF THE INVENTION

[0014] It is therefore, an object of the present invention to provide an improved electrically enhanced filtration process and filter, and process for manufacturing electrically enhanced filters and filtration systems and the individual components of these filters and filtration systems.

[0015] It is another object to provide electrically enhanced filtration with a deep filter exhibiting high surface area in a manner that enables the creation of stable and uniform collection field strengths while suppressing arcing across the filter media.

[0016] It is yet another object to provide electrically enhanced filtration with a deep filter

that exhibits a high surface area in a manner that enables the creation of stable and uniform collection field strengths in a safe manner.

[0017] It is still another object to enable electrically enhanced filtration with a deep filter that provides a high surface area in a manner that allows the creation of stable and uniform collection field strengths by using an ionizer that is not prone to back corona discharge or ionizing field cancellation effects attributable to the collection of highly resistive dust on the ground electrode plate of the ionizer.

[0018] It is still yet another object to enable electrically enhanced filtration with a deep filter that provides a high surface area and allows the creation of stable and uniform collection field strength in a manner that it is at least as effective as the filtration achieved by contemporary devices.

[0019] It is a further object to enable high efficiency filtration with very low pressure drops and low resistance to air flow, by electrically enhancing the performance of deep V-pack filter elements.

[0020] It is a yet further object to provide a high efficiency particulate air (i.e., a HEPA filter) with about half the pressure drop of the best currently available deep V-pack HEPA filter elements.

[0021] It is a still further object to provide a filter that inhibits the growth of microorganisms caught on the filter and that has the potential to actually kill some bacteria entering the filter.

[0022] It is also an object to provide a process for constructing a deep V-pack filter element that can be used as an effective and safe electrically enhanced filter.

[0023] It is an additional object to enable high efficiency filtration with higher dust holding capacity and thus life of the filter, by electrically enhancing the performance of deep V-pack filter elements.

[0024] These and other objects may be achieved with a deep V-pack filter element bearing a charge transfer electrode (*i.e.*, a CTE electrode) formed on the obverse side of the filter media and a ground potential electrode formed on the reverse side of the filter media. The filter element may be disposed within the flow of a stream of transient air directed toward the obverse side of the filter medium bearing the charge transfer electrode oriented toward the upstream side of an electrostatically stimulating filtering apparatus, while an ionizer with a single ionizing electrode, or in alternative embodiments, a plurality of ionizing electrodes

positioned in an array, is spaced-apart from opposite facing charge transfer electrodes. The ionizing electrode is located between the control ground electrode and the charge transfer electrode. A control electrode maintained at a local reference potential, is spaced apart and upstream from the ionizing electrode.

BRIEF DESCRIPTION OF THE DRAWINGS

[0025] A more complete appreciation of the invention, and many of the attendant advantages thereof, will be readily apparent as the same becomes better understood by reference to the following detailed description when considered in conjunction with the accompanying drawings in which like reference symbols indicate the same or similar components, wherein:

[0026] Figs. 1a, 1b and 1c respectively show an elevational view of the inlet side, an enlarged elevational view of that outlet side, and an overall elevational view of an outlet side of an electrically enhanced filter constructed according to the principles of the present invention;

[0027] Figs 2 shows two of the many variations in the alignment of electrodes that are possible in the construction of contemporary filtering devices;

[0028] Fig. 3 is a two coordinate graph illustrating the amplitude of voltage induced on the upstream electrodes as a function of distance between the nearest ionizing electrode and the upstream charge transfer electrodes;

[0029] Figs. 4 and 5 are schematic diagrams illustrating the necessity for the charge transfer electrode of the electrical enhancement of deep V-pack filters as shown by Figure 5, in comparison with contemporary electrically enhanced, relatively shallow filters;

[0030] Fig. 6 shows an alternative configuration of an embodiment constructed according to the principles of the present invention;

[0031] Fig. 7 shows the details of an ionizing electrode mounted with a control ground electrode in an embodiment constructed according to the principles of the present invention;

[0032] Fig. 8 shows an alternative configuration of an embodiment constructed according to the principles of the present invention;

[0033] Fig. 9 shows an alternative configuration of an embodiment constructed according to the principles of the present invention;

[0034] Fig. 10 shows an alternative configuration of an embodiment constructed according

to the principles of the present invention;

[0035] Figs. 11A, 11B, 11C and 11D are enlarged, sectional views showing the different patterns of the electrical conductors and perforations within the electrical conductors, in various patterns that might be used as the charge transfer electrode or the downstream ground electrode for the filter element; is an enlarged view showing the printed lines that may be formed to serve as the charge transfer electrode on the filter element;

[0036] Fig. 12 shows an alternative configuration of an embodiment constructed according to the principles of the present invention;

[0037] Fig. 13 shows an alternative configuration of an embodiment constructed according to the principles of the present invention;

[0038] Fig. 14 shows an alternative configuration of an embodiment constructed according to the principles of the present invention;

[0039] Fig. 15 is an exploded view of ionizer and filter assemblies for use with an electrically enhanced filter constructed according to the principles of this invention;

[0040] Fig. 16 is a two coordinate graph illustrating corona onset occurring as a function of the voltage applied across an ionizing electrode as measured in kilo-Volts and the voltage induced on the charge transfer electrode in kilo-Volts;

[0041] Figs. 17A and 17B illustrate two of three techniques for constructing and installing filter material in the filter assembly; is an exploded view illustrating two alternate embodiments of filter media elements constructed according to the principles of the invention;

[0042] Fig. 18 is an elevation, cross-sectional view illustrating an assembly that can be used to mount single or multiples of filter elements and ionizers in air handling units;

[0043] Fig. 19 is an isometric view illustrating an arrangement of a typical housing for an embodiment of the present invention while Fig. 19A is a side view of an alternative embodiment of a grounding clip; and

[0044] Fig. 20 is a diametric view of an alternative configuration of an embodiment constructed according to the principles of the present invention with parallel pleats and curved apexes; and

[0045] Fig. 21 is a diametric view of an alternative configuration of an embodiment constructed according to the principles of the present invention, with curved apexes.

DETAILED DESCRIPTION OF THE INVENTION

[0046] As used in this description, the variable:

d_1 represents the distance between the ground control electrode 7 and the ionizing electrodes 8;

d_2 represents the separation between the charge transfer electrodes 8 and the ionizing electrodes 5;

d_3 represents the distance between the downstream ground electrodes 4 and the charge transfer electrodes 5;

d_4 represents the nominal depth of each fold as illustrated, by way of example, in Figure 12, of the filter medium 1, 16 or 17, as measured between the base of the fold to the longitudinally opposite apex of the fold; and

d_5 represents the nominal width of the base of each fold as exemplified by Figure 12, as measured between successive upstream apices of a fold.

[0047] Turning now to the drawings collectively, and particularly to Fig. 1a, which shows an elevation view of an inlet side of a filter assembly 31 for an ionizing field electronically enhanced filter 100 with the ionizer assembly removed, Fig. 1b which shows enlarged details of the downstream outlet side of filter assembly 31, and Fig. 1c which shows an elevation view of the downstream outlet side of filter assembly 31. Filter assembly 31 may be constructed with an exterior frame 24, that may be made of sheet metal or any other electrically conductive or non-electrically conductive material, enclosing an array formed by one, or more, deep accordion folds of a pleated filter medium 1 covered, on the upstream, or inlet side, by the pattern of a charge transfer electrode 5. Alternatively, the filter folds 52, may be formed using flat mats or felts with thickness 16, or thin paper sheets 17. In Figs. 1 and 2, the patterns of charge transfer electrodes 5 and downstream ground electrodes 4 are shown to resemble honeycombs in cross-section (as is better seen in Fig. 11); other patterns may be used for charge transfer electrodes 5 and downstream ground electrodes 4; the honeycombed pattern illustrated is only one of many perforated patterns that may be used for electrodes 4, 5 to cover the downstream and upstream exposed surfaces of filter material 1, 16 or 17. Note that in Fig. 1 only the lower portion of filter assembly 3 on the upstream side is visible. It should be noted that both the upper and the lower side of upstream surface portions of the filter assembly 31 of each pair of arms 52 forming each pocket of filter medium 1, 16 or 17 into a V-shaped fold 52 has the transfer electrode 5 applied to it. Arms

of the folds 52 may also be constructed with all of the several folds formed from the same part of the continuous layer of material 1, 16, or 17.

[0048] Alternatively, end caps 2a, 2 encapsulate filter medium 1, 16, or 17 and possibly one or more electrodes 4, 5 extend horizontally across the inlet and outlet sides, respectively, between side frames 24. End caps 2a force the entrance of particulate bearing air, indicated by arrows "A", into the V-shaped pleat packs 52 only. Pleat packs 52 may be joined at an apex 50. End caps 2 on the outlet side also restricts passage of the air to the V-shaped pleat packs 52. Consequently, particulate laden air drawn or pushed into the inlet side of filter 31, passes through the broad planar areas provided by the several folds of filter medium 1, 16 or 17.

[0049] Charge transfer electrodes 5 may be formed on the exposed outer, or upstream, surfaces of the V-shaped folds 52 on the inlet side of medium 1, 16 or 17, while downstream ground electrodes 4 may be formed on the exposed, opposite outer, or downstream, surfaces of the V-shaped folds 52 on the outlet side as illustrated by Figs. 1b, 1c. Electrodes 4, 5 may describe honeycomb grid patterns as shown in Figs. 1a-1c, or any of various screen or grid patterns that cover the opposite exposed parallel sides of medium 1, 16 or 17, to each form a discrete, continuous electrode 4, 5 that may be maintained at a single, constant and uniform potential. Alternatively, when end caps 2 and 2a are used, electrodes 4, 5 may be formed by inserting flat or V shaped perforated metal plates within the V forming folds 52. The induced voltage on the electrodes 5 is then dependent on the smallest value of d_2 achieved. Thus an advantage of uniform charge transfer potential across the filter medium is achieved. The downstream ground electrodes 4 are then maintained at ground potential by use of a grounded clip or clips or other mechanical means. Electrodes 4 and 5 are electronically isolated from one another so that they may be maintained at different electrical potentials during operation of filter 100, and are physically separated by the thickness d_3 of the medium16 or 17 of filter 1.

[0050] It is contemplated that downstream electrode 4 will be maintained at a local ground potential, while charge transfer electrode 5 will be maintained at a potential that has a higher magnitude than downstream electrode 4. Electrode 4 may therefore, be electrically connected to the sidewalls formed by frames 24 and to end caps 2, but electrode 5 must be electrically isolated from electrically conducting end caps 2a and from the electrically conducting frames 24 by air gaps 6. If end caps 2a are made from a non-conductive and dielectric material, then

electrodes 5 may contact end caps 2a. Similarly, if the filter's frame 24 is made of non-conductive and or dielectric material, then the electrodes 5 may contact the frame 24. As is explained subsequently herein in the detailed discussion that accompanies Figs. 4a through 19, an ionizer assembly 30 constructed with a plurality of parallel ionizing electrodes 8 maintained at a high voltage relative to the local ground, may be attached to the exposed flanges that frame the inlet of filter assembly 31, to locate individual ones of ionizing electrodes separated by identical air gaps having preferably identical constant distances, d_2, from a corresponding planar surface of charge transfer electrode 5. Alternatively the ionizer assembly 31, may have guides made using angle metal tabs that guide the assembly of ionizer 31, as described above, without fastening the ionizer 30, to the filter frame, 31. The filter frame 31 and ionizer 30 are then fastened within a filter housing by means of bolts or other means that compress the ionizer 30, frame 31 and thus also compress the filter gasket 26 against the seal plate 34. The consistency of the values of the resulting air gaps, d_2, allows an uniform voltage to be induced onto charge transfer electrode 5, if the charge transfer electrodes are not continuously formed (*e.g.*, formed by using individual plates of V-shaped plates), thereby establishing an uniform electrostatic field that extends across the thickness d_3 of medium 16 between charge transfer electrode 5 and downstream ground electrode 4.

[0051 Referring now to Figs. 2 and 3, I have found that with embedded upstream corrugated spacers, which are inherently electrically isolated from one another, variations occurring in the induced field depends on the distance d_2 between electrodes 8 and the upstream corrugated spacers at a fixed applied potential to electrodes 8. When both the tolerances in media folds and aluminum spacers are taken into account, this can mean large variations in induced potentials and hence in collection field strength and therefore in filtration performance within various sections of the filter medium.

Typically, the folded glass fiber media used in filters with aluminum separators in structures such as taught by Cheney '736, is about 0.02" thick. I have found that it is very difficult, if not impossible, to achieve identical folds that is, folds with less than 0.08" variation in fold length and identical corrugated separators, that is, tolerances of corrugation angles and cut lengths that are respectively better than five degrees and lengths better than 0.06". Recognizing that ~~in~~ the induced electrical field depends on the least distance d_2 from the ionizing electrode to the upstream corrugated spacers at a fixed applied potential to the wires, when both the tolerances in media folds and aluminum spacers are taken into account,

there are concomitantly large and undesirable variations in induced potentials and hence in collection field strength, and therefore erratic filtration performance within various sections of the filter medium. Moreover, the variation in the upstream corrugated spacers alignment with respect to the downstream spacers is responsible for a lack of uniform performance of the filter; the performance will vary from media section to section since the collection field strength will be inversely proportional to the local distance d_3 between the upstream and the downstream electrodes. This means that some sections of the filter will have very low enhancement of filtration efficiency. If deeper pleated spacers are used, this lack of uniformity and the irregularity and variation are worsened.

[0052] A high potential for sparking with contemporary filtering devices such as those of Cheney and Spurgin disclosed in their U.S. Patent No. 4,781,736 occurs because the voltage induced on the upstream electrodes is a function of distance between the upstream electrode and the ionizing electrode. Keeping in mind that, in order to assure the prevention of sparking in such thin media, a voltage higher than about 0.35 kilovolts can not be induced on the upstream electrodes when peaks of the upstream and downstream corrugations are aligned, as shown in Figure 2. Referring to Figure 3, one can clearly see how daunting the task of maintaining such a precise gap between each and every one of the upstream electrodes and the inducing wire. Since the aluminum separator electrodes are simply (and thus erratically) placed, unsecured, between the media folds, it is highly likely that some of the electrodes will be too close and cause a higher surface potential on those upstream corrugated electrodes that are closer to the high voltage wire, resulting in corona discharge and sparking at points where the peaks of the upstream and downstream corrugations of the electrodes align. Sparking may burn holes in the filter media and has the potential to cause a fire if the sparking is continuous. In tests that I have done, it was practically impossible to get a filter element that had been constructed with aluminum separators to function without sparking while simultaneously achieving a significant improvement in filtration, especially under higher humidity (*i.e.*, 60% or higher) conditions. Even if an ideal manufacturing method was developed for making filters with aluminum separators separating neighboring layers of the filter medium, contemporary practice has been unable to predictably control the distance between corrugated electrodes and the high voltage wire so that no sparking occurred and, at the same time, filtration performance was significantly improved. Moreover, contemporary practice with aluminum separators still results in significant variations the alignment of the upstream and

downstream separator peaks and valleys and thus the distance d_3 between the adjacent upstream and downstream electrode surfaces and, therefore, the strength of collection fields across different portions of the filter.

[0053] I have found that excessive leakage current occurs in contemporary filtering devices because the filter medium is highly porous (*e.g.*, porosity > 95%) when the minimum distance between the high voltage wire and the downstream corrugated electrode is not significantly greater than the distance between the wire and the upstream corrugated electrode, causing a considerable amount of leakage current towards the downstream corrugated electrode which is at ground potential. This will make the device inefficient. In this case, current leakage is exasperated and therefore efficiency is further reduced when the glass filter paper absorbs moisture during occasions of higher humidity.

[0054] Now consider the variation in the alignment of the peaks and valleys of the upstream corrugated spacers with respect to the adjacent downstream spacers. Fig. 2 shows two of the many variations in alignment that are possible. In one case the alignment of the peaks are off by approximately 45 degrees. This results in Min1 and Max1 distances d_3, between the upstream and the downstream spacers. In this case the performance will vary from media section to section since the collection field strength will be inversely proportional to d_3 (collection field strength = Vinduced / d_3). Now consider the case (which must be considered because this will occur often within the filter media folds) when the spacers are mis-aligned by about 180 degrees - *i.e.,* peaks will coincide or almost coincide as shown in bottom section of Fig. 2. In this case of Min2, d_3 is equal to the media thickness and at Max2, d_3 is equal to twice the depth of the spacers. The maximum induced voltage on the upstream corrugated spacer electrode in their device can only be about 0.35 kilo-Volts in order to safely eliminate sparking through the media (thereby preventing damage to the media and avoiding a fire) towards the opposite corrugated electrode spacer (which is also within the pleat) at ground potential on the other side of the pleat at the point where the peaks are aligned as in Min2 d_3. This corresponds to a collection field strength of about 17 kilo-Volts/inch, but only when the peaks of the upstream corrugated electrode are facing (see Fig. 2) the corrugated counter spacer electrode peaks (as in Min2] d_3) on the opposite side of the media. A collection field strength of about 12-15 kilo-Volts/inch, is desirable for effective collection of particles on the filter media. Consider now that for the Max2 d_3 section of the media, the collection field strength at that section will be 0.35 kilo-Volts/0.52" = 0.67 kilo-Volts/inch, if 0.25" separator

corrugations (which are the smallest size corrugations) are used. This collection field strength 0.67 kilo-Volts/inch is negligible for efficient filtration of particles from the air stream. It will not be possible to induce an adequately higher voltage on the upstream corrugated electrode to compensate for this, because then the field strength at the Min2 d3 section will exceed the safe no sparking or arcing limit. This means that this section (Max2 d3) of the filter will have very low enhancement of filtration efficiency. If deeper pleated spacers are used, this situation is worsened. Of course, it should be noted that all sorts of situations in between these two situations can exist. Essentially, this results in a non-uniform and low overall performance. Keeping in mind that filters are mostly rated by their weakest performing section, this structural configuration will not result in high enough filtration enhancement.

[0055] Turning now to the issue of whether the structural configuration using embedded separators shown in Fig. 2 has an unnecessarily high likelihood for sparking, Fig. 3 shows the voltage induction on the upstream spacer electrodes as a function of distance from a wire electrode. One set of measurements, represented by rectangles, was taken for four different values of d_2 separation, with the ionizing electrode at fifteen kilo-Volts, while a second set of measurements was taken for the same four different values of d_2 with the ionizing electrode at seventeen kilo-Volts. Both sets of measurements were able to be fitted with linear curves, labeled respectively as 15 kV fit and 17 kV fit. Keeping in mind that the upstream electrode cannot be induced to a voltage higher than about 0.35 kilo-Volts, one can clearly see how daunting the task of maintaining such a precise gap between each and every one of the upstream electrodes and the inducing wire. In the structural configuration of Fig. 2, the electrodes are simply placed, unsecured between the media folds; it is highly likely that some of the electrodes will be closer than the target distance d_2 by as much as 3/16 of an inch. This will result in higher surface potential on those upstream corrugated spacer electrodes that are closer to the high voltage wire, resulting in corona discharge and sparking at points where the peaks of the upstream and downstream corrugations of the electrodes align as in Fig. 2. Sparking can also occur at other upstream and adjacent downstream alignments depending on the distance d_2 which would result in higher induced voltage on the upstream separator electrodes if d_2 was reduced due to placement of the separators. Sparking will cause burn holes in the filter media and possibly cause a fire if the sparking is continuous. Exemplary efforts in the art such as Cheney '736, suggest the use of existing, commercially available aluminum separators embedded in deep pleat filters. I have found that in tests that I have

done on filters constructed, with embedded electrically conducting separators, it was not possible to get an aluminum separator filter to function without sparking and at the same time achieve a significant improvement in filtration, especially at normal higher relative humidity (~60% and higher). Even if a close to ideal manufacturing method for making such filters was to be developed that was able to control the distance between corrugated electrodes and the high voltage wire so that no sparking occurred, the resulting embedded filter would still demonstrate significant variation in surface potential and, therefore, variation in collection fields across different portions of the filter.

[0056] Since the filter medium used in embedded electrically conducting separators are highly porous (*e.g.*, porosity > 90-95%) and the minimum distance. These definitions have nothing to do with the downstream ground between the high voltage wire and the downstream corrugated electrode is not significantly greater than the distance, between the wire and the upstream corrugated electrode, there will be a considerable amount of leakage current towards the downstream corrugated electrode which is maintained at ground potential. Any leakage current will make the device inefficient. This situation is worsened when the glass filter paper absorbs moisture as a result of high humidity.

[0057] In order to prevent sparking towards the frame material, the frame material in the practice of Cheney '736 must be non-conductive because the aluminum spacers of the upstream corrugated electrodes will have a high probability of contacting the frame material. Typically, wood or particle board products are used. Most current manufacturing methods have switched to the use of aluminum or metal channel frames since these are non-particle shedding, result in better seals to the media, and are not flammable. Cheney '736's wood is a relatively dirty material and thus less suitable for cleanroom applications.

[0058] It should be noted that Cheney '736 does not describe any electrode gap values or ranges of voltages used in any of the configurations, nor does it provide any results showing the efficacy of the embodiments disclosed. It is highly likely that these practical difficulties and performance limitations of the Cheney and Spurgin is the main reason why such a device has never been successfully commercialized. Additionally, aluminum separator folded filter type filter elements have become unpopular because these filters tend to tear under airflow, especially during startup, due to the sharp aluminum separators within the folded media operation.

[0059] Figs. 4 and 5 schematically illustrate several features implementing the principles

of the present invention as two possible configurations of an ionizing, electrically enhanced filter modified according to the principles of the present invention with generally non-conductive filter media. A perforated, electrically conducting charge transfer electrode 5 formed as a continuous grid, is placed upon and borne by the upstream surface of filter medium 1; electrode 5 is electrically isolated from direct conduction with a local reference potential such as ground, and from any counter potential electrodes 4, 7 (which may be maintained at a reference, or ground, potential) and from the ionizing electrode 8. I have found that tests show that the surface potential achieved on charge transfer electrode 5 with the embodiment shown in Fig. 4 is the same as the surface potential on the peaks of the filter medium in the absence of electrically conductive, perforated electrode 5, which is the same result obtained in Jaisinghani U.S. Patent No. 5,403,383. The results are summarized below in Table I:

<Table I>

Configuration	Applied Voltage on Wires kilo-Volts	Surface Potential due to Charge Transport, kilo-Volts	Electrically Enhanced Filter Efficiency of 95% Media
Without CTE (5,403,383)	17	10.9	99.99%
With CTE	17	10.8	99.99%

[0060] Basically, these results clearly establish that in the "flat" or shallow depth filter configurations illustrated by Fig. 4, the addition of charge transfer electrode 5 neither aids nor affects the operation or performance of the EEF in any significantly manner.

[0061] Turning now to Fig. 5, if filter element 1 and charge transfer electrode 5 are both tilted at an oblique angle relative to ground control electrode 7 and the nominal direction of impinging airflow indicated by arrow A, and another filter medium pack 52 is added to form a V-shape, then the embodiment of this invention shown by Figs. 6 and 8 results. In this embodiment, the distance between ionizing electrodes 8 and the control electrode 7, d_1, primarily determines the particle charging field strength, that is, the corona generation, which results in ion formation and charging of incoming particles carried by air entering filter 1 in the direction of arrow A.

[0062] The invention differs in the manner the particle collection field strength across the

filter medium is established. In Jaisinghani U.S. Patent No. 5,403,383 the upstream plane of the filter medium achieves a uniform charge since the distance between the ionizing wires and the upstream plane of the filter is uniform. In this invention, since the filter medium is an a V-pack formation, the closest portion of the filter medium would have the highest influx of charge while the furthest section would have the lowest or negligible amount of charge. In order to overcome this difficulty the charge transfer electrodes 5 (*i.e.*, CTE's 5) are utilized - the discharge of ions around the ionizing electrodes 8 is collected on the electrically conductive CTE 5, primarily at the portion of CTE 5 closest to ionizing electrodes 8. CTE 5 is electrically conductive, and therefore achieves a constant and high enough potential across the upstream face of the V-pack filter media for proper collection of particles on the filter medium. This is also true if instead of the V-pack filter configuration, the other configurations shown in Figs. 7 through 13 are used. Without the use of CTE 5, the deep filter would not function adequately because the collection field at the far ends of the V-pack (closer to the apex) would be too low.

[0063] The mechanism involved is not simple electrical induction. Referring to Table II and Fig. 16, the charge is transferred well into the exponential or corona generation portion of the curve. Unlike the Cheney and Spurgin, the resulting potential on CTE 5 is at least an order of magnitude (actually two orders of magnitude in the example shown in Table II) higher than the estimated potential that could safely be induced on the separators of the Cheney and Spurgin reference. The charge is eventually transferred across the filter to the downstream ground electrodes via the small, but finite conductivity of the generally non-conductive and dielectric filter medium. There is a net equilibrium charge accumulated however, and this results in a high surface potential, with a magnitude that is in between that of the voltage applied to the ionizing electrodes and the potential of the downstream ground electrodes, that are typically at ground potential. CTE 5 may be made of a conductive material such as aluminum or other metal, so that the potential is constant across the entire face of CTE 5. Thus the minimum distance, d_2, controls the value of the CTE potential for any given applied potential on the charging corona wires. Since the downstream ground electrodes and the CTE 5 are essentially parallel because they run along the planes of the filter media, the collection field strength (V_{CTE} / d_3) is high enough when compared to that of the flat configurations of contemporary design and also stable and constant across the filter medium, and without risk of spark discharge across filter medium 1.

[0064] The charging device, or ionizer assembly 30, significantly ameliorates the cancellation of the ionizing field (V_{app}/ d_1) caused by the capture of highly resistive dust on the upstream control electrode. In the practice of this invention, the particles of dust would have to travel against the direction of the airflow of transient air through interstices 190 in order to accumulate on ground control electrode 7. In many contemporary designs however, the ground electrodes are parallel to the path of air flow. Consequently, the dust particles that enter the system are close to the plates and are more easily captured on the plates. The resulting accumulation of these highly resistive dust particles often causes field cancellation and back corona discharge in contemporary devices.

[0065] Fig. 6 illustrates a deep V-pack arrangement of filter medium] arranged in a pleated configuration. This electrode configuration enables use of deep filter] in a safe, efficient and risk free manner - something that is not possible with contemporary designs. In this V-pack arrangement, the layer of filter paper may be repeated folded to form a pleated filter medium 1 which exhibits numerous folds or pleats and undulates alternately between the plane of downstream electrode 4 and upstream electrode 5. The extreme ratio between the length of each pleat of medium 1 within the V-pack to the fineness of the pitch between successive pleats enables the V-pack to contain much more filter media while providing a lower pressure drop along the path of the transient air flow. Filter medium 1 is itself not deep, but is configured into a V-pack arrangement that is quite deep. Typically, the pleat length or pleat depth used is between 0.5" - 2" in such V-packs though other pleat depths may also be successfully used within the scop of this invention.

[0066] Referring collectively to Figs. 6 and 10, a set of CTEs 5 are located on the upstream face of filter medium 1 and spaced apart from the ionizer wires 8 by a distance d_2. The charge transfer electrodes 5 should have no electrical contact with any other electrically conducting member. If the upstream end caps 2a that hold the V-packs in place are metal, then a gap 6, of about 0.25" to 0.5" (depending on the applied high voltage) is maintained between the end caps 2a and charge transfer electrode 5. If the end caps 2a are made from non-conductive or dielectric material however, then there is no need for such a gap 6. On the downstream side, a set of perforated downstream ground electrodes (DGE) 4, are applied to filter medium 1. In this case it is actually preferred that the downstream end caps 2 be made of metal and that the downstream ground electrodes be in direct electrical contact with metal end caps 2. An electrical charge is transferred to CTEs 5 by ionizer assembly 30. Ionizer assembly 30 is a

frame that is positioned so as to hold ionizing electrodes 8 preferably (though not necessarily) parallel to and spaced apart by a constant, fixed minimum distance d_2 from the CTE 5.

[0067] Referring again to Fig. 6, the gap d_2 between high voltage ionizing electrodes 8, and CTE 5, is such that the field strength across the filter medium 1, (defined as CTE potential divided by the distance d_3 between CTE 5 and the downstream ground electrode (DGE) 4), is essentially the same as the field strength across medium 16 of the flat configuration as described in Jaisinghani '383. Additionally, the gap d_1 between the high voltage ionizing electrodes 8, and the control electrode 7, is such that charging of airborne particles within transient air is achieved - *i.e.*, the charging field strength (defined as the potential applied to electrodes 8 divided by d_1) is similar to the field strength used in Jaisinghani U.S. Patent No. 5,403,383.

[0068] In the basic mechanism of filtration enhancement, ionizing electrodes 8 are positioned within charging range d_2 of charge transfer electrodes 5, and charge transfer electrodes 5 become electrically charged by ion flow from the corona of ionizing electrodes 8. Downstream ground electrode 4 is maintained at a local ground potential; consequently an electrical field is established across filter medium 1, between charge transfer electrode 5 and downstream ground electrode 4. The incoming particles are charged by the first ionizing field, V_{app}/d_1, and some of the bacteria entering may be killed in this zone. Ionizing electrodes 8 transfer charge to the CTEs 5, and thus an adequate and safe, non sparking high collection field, V_{CTE}/d_3, is easily achieved across filter medium 1. Some of the biological particles, such as bacteria, collected on the filter will be killed by the electrical fields. However, the growth of almost all other common airborne biological particles collected on the filter medium will be inhibited due to the fact that these particles are held indefinitely under the high electrical fields. This provides a substantial benefit to the quality of indoor air. Typical filter V-pack filter assemblies 31 suitable for use in this invention are available from Camfill-Farr under their Filtra 2000 series, or are available from other manufactures such as Filtration Group, but without the embedded electrodes 4 and 5 necessary for this invention.

[0069] The operation of this electrically enhanced deep filter attains a reduction in the penetration of particles through the filter medium 1 by about two to three orders of magnitude. Consequently, a significantly lower resistance to the flow rate of transient air (as compared to the non-enhanced filter as in mechanical filtration having the same penetration) and an

increase in filter life by about a factor of between about two to three is also achieved. The increase in the filter's life, as compared to a mechanical filter exhibiting the same penetration, is due to filter assembly 100 exhibiting a lower initial pressure drop and due to the formation of dendrites caused by the electrical field resulting in a higher porosity formation of dust layers on filter medium 1, which preserves the lower pressure drop across filter assembly 31.

[0070] The configuration using a V-pack filter assembly 31 illustrated by Fig. 6 may be compared to an embodiment of Jaisinghani U.S. Patent No. 5,403,383 in Table II. Embodiments of Jaisinghani '383 conveniently serves as a benchmark of electrical enhancement of particle removal efficiency, albeit with the concomitant deficiencies in the embodiment of Jaisinghani '383 noted in Table II.

<Table II>

Parameter	5,403,383	Deep V-pack w/ CTE
Vapp, kilo-Volts	17	12.5
d_1, inches	1.45	1.0625
Ionizing Field Strength, kilo-Volts/in	11.72	11.76
d_2 min dist from wire to media or CTE, inches	0.625	0.5625-0.625
Media peak or CTE surface potential, kilo-Volts	10.9	5.72
Media depth d_3, inches	2	1" in a - 11.5" deep V-pack
Collection field strength	5.45	5.72
Filtration Efficiency @ 0.3 micrometers @ 300 fpm, %	99.97-99.99	99.99+
Filter Pressure drop @ 300 fpm face velocity	0.85" WC	0.25" WC
Filtration Efficiency @ 0.3 micrometers @ 600 fpm, %	99.93	99.99
Filter Pressure drop @ 600 fpm face velocity	1.75" WC	0.5" WC

In both cases the filter medium used has a non-enhanced filtration removal efficiency of between approximately 92-95% for airborne particles that are 0.3 micrometers in diameter or larger.

[0071] Fig. 3 illustrates how the CTE potential in a deep V-pack configuration is

determined by the distance d_2 between the ionizing electrodes 8, and CTEs 5, for any one particular set of values for V_{app} (the voltage applied to electrodes 8) and d_1. Fig. 16 on the other hand shows how the magnitude of the potential at CTE 5 (and therefore the collection potential across CTE5 and DGE4) increases as a function of the amplitude of the voltage applied to electrodes 8, for constant values of d_2 and d_1. It is important to note that this CTE potential as a function of applied potential is accurate only when used in conjunction with a control ground electrode maintained at a distance d_1 from the ionizing electrodes. As illustrated by Fig. 16, there is a region where V_{CTE} is very low (near zero) and linear with respect to V_{app}. Once the V_{app} is greater in magnitude than the corona onset voltage (the corona onset voltage depends also on d_1) however, then the value of V_{CTE} increases exponentially with respect to V_{app}. This indicates that the charge transfer mechanism between ionizing electrodes 8 and charge transfer electrodes 5 is charge transport rather than simple electrical induction.

[0072] The embodiment illustrated by Fig. 6 attains higher performance at higher flow rates with lower pressure drop or flow restriction as compared to both conventional filters and embodiments of Jaisinghani U.S. Patent No. 5,403,383.

[0073] Two other configurations are shown by Figs. 8 and 9. In Fig. 8 CTE 5 is held against the upstream face of relatively thick (typically exhibiting thicknesses from 0.125-2"), non-pleated filter medium 16. This is one distinction between the embodiment illustrated by Fig. 8 and the configuration of Fig. 6. It is important to note that in these configurations CTE 5 is made of flat metal plates perforated by numerous interstices 160 accommodating passage of transient air, with every part of CTE 5 positioned essentially in direct physical contract with the upstream outer exposed, major surface of filter medium 1 or 16; CTE 5 does not function as a spacer and hence need not be in corrugated form as the aluminum spacers used in the contemporary designs represented by Cheney *et al.* U.S. Patent No. 4,781,736. As discussed previously, with spacers that are corrugated, the field strength across the filter medium is non-uniform and can result in sparking and the burning of holes in and through the filter medium.

[0074] Fig. 8 shows the thicker, non-pleated medium 16. An example of this would be the use of flat, continuous fiber glass mats or felt of polymeric or other materials lying between essentially parallel electrodes 5, 4 in non-pleated form as a linear continuum extending between end-caps 2, 2a over the length of each pleat. In this configuration, although end caps

2, 2a are shown, it is not necessary for end caps to be used. Medium 16 can simply be folded at each end of a pleat, around the downstream ground electrode 4 or the V-shaped CTE 5, as shown in the case of the relatively thinner thickness d_3 of paper medium 17 illustrated by Fig. 9. If flat, conductive end caps 2a are used in each pleat of the construction of the Fig. 8 embodiment however, CTE electrodes 5 must have a gap of approximately, 0.25" to 0.5" between the end cap and the edge of the CTE 5, depending on the design CTE voltage, as is shown by Fig. 8.

[0075] Alternatively, the CTE 5 may contact a non-conductive end cap 2a. If, however, no end caps 2a are used (as in the wrap around electrodes shown in Fig. 9), then a gap 6 of 0.1" to 0.25" (depending on the CTE 5 design potential and the filter media thickness) is maintained between the ground control electrode 7 and the CTE 5 edge closest to the ground control electrode 7. This gap is necessary so as to prevent sparking from the CTE 5 to the ground control electrode 7.

[0076] Fig. 9 shows the configuration using non-pleated, folded, thin paper medium 17. When filter medium 17 is in a very thin paper form, even when in the non-corrugated spacer electrode configuration shown, it can become extremely difficult to assure that no sparking or electrical discharge occurs anywhere across the structure of medium 17. In that case, a small air gap between CTE 5 and filter medium 17 may be maintained so as to enable stable and safe operation. Alternatively, the air gap may be applied to the DGE 4 instead of CTE 5 to create the same effect. The gap may be maintained with spacers 18 made of a relatively higher electrical resistance glue beads, although other higher resistance polymeric spacers may also be used. It should be noted that the spacers are not separating the folds of the filter medium 17, but are spacing apart electrodes 5 or 4 from the filter medium 17. The addition of the gap enables the device to operate at a higher and more stable potential difference between CTE5 and ionizing electrodes 8. Effectively, the distance d_3 is increased by the non-electrically conducting, insulators 18 serving as spacers between CTE 5 and the upstream outer surface of medium 17, and this larger distance d_3 is compensated for by applying a higher, and more stable CTE potential which is controlled by distance d_2 and the ionizing field strength V_{app}/d_1. This assures proper and stable collection field strength for operation without arcing. The CTE may wrap around the filter medium 17 provided however that a minimum gap of 0.1-0.25" is maintained between the CTE 5 and the ground control electrode 7. Alternatively, the electrodes 5 may be shorter than the folds of the filter medium 17 by

approximately 0.1 to 0.25" at the end closest to the ionizing electrodes 8. This gap depends upon the design value of the CTE 5 potential and the thickness of the filter medium.

[0077] Turning now to Figs. 10 and 11A, 11B, 11C and 11D, either or both the downstream ground electrode 4 and the CTE 5 may be deposited as an electrically conductive pattern of electrical conductors 150 that form a grid that is perforated by numerous interstices which accommodate a flow of air or other gaseous influent through CTE 5 and the material 16, 17 of filter medium 1. Conductors 150 may be printed directly onto either or both the upstream and downstream outer surface of filter medium 1, 16 or 17 in a grid such as a honeycomb pattern shown by Fig. 11C, by using a conductive ink or paint with appropriate openings to simulate a perforated electrode. Conventional photolithographic or stamping techniques may be used to create such a pattern on either or both the downstream and the upstream surface of filter medium 1, 16 or 17. In this case there is no necessity of using metal plates for CTE 5 and DGE 4, although plates of an electrically conductive material could also be used if the pleated configuration was used with CTE 5 deposited on the upstream surface of filter medium 16 or 17 and if the conductivity of the printed CTE 5 was not high or had an intermediate level. In that case, the printing will enable a higher collection field strength without the application of a higher amplitude of V_{CTE} or without reducing the value of d_2 to an untenably low value. All other aspects of this embodiment may be constructed similarly to those illustrated by Figs 6, 8 and 9. If end caps 2a are made from a non-electrically conducting material such as plastic, no gap 6 is necessary. If end caps 2a 6 are made from an electrically conducting material, the width of gap 6 is dependent upon the charge held by CTE 5.

[0078] A dual filter layer configuration is illustrated by Fig. 12 and may be constructed according to the principles of the present invention, with an electrically conductive fibrous layer 19 which serves as a pre-filter, an electrically conductive or relatively conductive, pre filter layer 19 or a porous paper layer 19 may be used, instead of the electrically conductive metal CTE 5, on the upstream exterior surface of the non-electrically conductive filter medium 17. This conductive fiber configuration can also function as a pre-filtration device. Although Figs 12 only shows a dual media 19, 17 with the flat filter medium 17 configuration, it should be noted that this method can also be applied to the pleated configuration of medium 1 illustrated by Fig. 6. It should be noted that when using dual media 19, 17 configuration, it is important that a small gap 6 of between approximately 0.1 to about 1.0 inches be

maintained between ground control electrode 7 and conductive medium 19 which functions as the CTE charge transfer electrode.

[0079] Turning now to Fig. 13, resistive control of transfer electrode 5 may be established in order to limit the CTE 5 potential other than the local reference, or ground potential. Instead of letting CTE 5 float or be totally electrically isolated, CTE 5 may be connected to a local reference potential such as a ground or to the opposite downstream ground electrode 4 via a high resistance resistor R_{20} in the mega-ohm range. Resistor R_{20} is coupled in parallel to the much higher resistance of the medium 16, 17 of filter 1. This will limit the accumulated charge on CTE 5, resulting in a lower or limiting potential at CTE 5. Thus, technique may be used to control the CTE potential in addition to varying the distance d_2. This technique may be useful when d_2 is small and slight and precise variations of d_2 are not practical. The use of resistor R_{20} provides a secondary way of controlling the collection field strength and also ensuring the safety of filter device 1 by inhibiting arcing. Fig. 13 shows resistor R_{20} applied to the configuration detailed in Fig. 6. This technique may be used in one or more of the several possible combinations with the other basic configurations described here using either flat or deeply pleated V-packs.

[0080] Referring now to Fig. 14, the ionizer is constructed to provide separate ionizer and charge transfer fields. In the embodiments illustrated by Figs. 6, 8, 9, 10 and 12, the ionizer electrodes 8 serve to both ionize the incoming gas or air based on V_{app} and d_1 and to transfer the charge to the CTE 5, in dependence on d_2. In order to separately control ionization, and the charging of airborne particles and the charge transfer to the CTEs 5, a separate set of electrodes 184 on separate ceramic standoffs 13 may be used so as to maintain electrodes 184 at a distance of d1 from the control ground electrode 7. The shorter standoffs are used to suspend ionizing electrodes 184 for the particle charging field, while the longer standoffs are used to suspend the ionizer wires 8 used to transfer the charge to the CTE 5 at a distance of d2. Alternatively, a totally separate ionizer may be used and a totally separate charge transfer set of electrodes 8 may be used with separate high voltage connections to particle charging electrodes 184 and ionizing electrodes 8. In both these configuration, it may be necessary to use two different high voltage power supplies, depending on the actual design.

[0081] Referring now to Figs. 1, 6, 15, 17, 18 and 19 collectively, the configurations described in the foregoing paragraphs may be put into practice with either deep V-pack pleated filters made with glue beads, ribbon separators or a separatorless mini-pleated filter

medium 1 illustrated in Fig. 6, or with an unpleated, continuously flat filter medium 16, 17, regardless of whether the filter medium is constructed with thick felt of fiber mat 16 or with a thinner layer made of a porous material such as paper 17, as is shown by Figs 8 and 9.

[0082] Within each of these embodiments it is understood that variations such as the printed CTE 5 as shown in Fig. 11, resistive control of CTE potential as shown in Fig. 13, dual relatively conductive media CTE as shown in Fig. 12 and alternate ionizer with separate CTE charging as shown in Fig. 14, may be incorporated, in different variations.

[0083] Figs 1a, 6, and 15 show a typical V-pack filter constructed by using filter medium packs 1, of approximately 1" deep glue bead or ribbon separator filter medium mini-pleats or separator-less mini-pleats arranged in a multiply folded, deep V formation so that individual neighboring pairs of the folds form the apex of the V within a downstream end-cap 2. The packs are typically sealed within the end cap using a polymeric flexible adhesive 3 such as urethane plastisol. The transverse surface of the packs and the ends of the end-caps are sealed to the filter frame 24 by potting the packs and the end-caps to the frame of the V-pack using similar adhesives. The frame of the filter is typically made using aluminum or galvanized channels and clips 27 which hold it together. The insides are potted with a urethane or other similar adhesive to form a solid frame that is sealed to prevent detectable leakage.

[0084] End caps 2 shown by Fig. 1b on the downstream side of the filter are preferably made of an electrically conductive metal, which is in electrical continuity with the metal framing material or channel that encompasses the filter as a housing. The downstream ground electrode plates 4 are inserted within end caps 2 in electrical contact to provide electrical continuity with end caps 2 which are maintained in electrical continuity with the conductive frame of the filter. Thus, only one point on the frame of the filter needs to be grounded or set to a opposing potential in order that all of the downstream ground electrodes plates 4 will be at the same potential. This grounding may be typically accomplished by a metal grounding clip 47, which contacts the filter end caps as the filter is tightened against the seal plate 34 as shown by Fig. 19. Different mechanical devices that enable ground contact may also be used in lieu of grounding clip 47. If the filter frame or end cap 2 is made of non-conductive material or if contact of the downstream ground electrode 4 with the end caps 2 or contact between end caps 2 and filter frame is not feasible, then instead U-shaped grounded metal or conductive clips may be used to make frictional contact with each of the ground electrodes 4 at the apex of the V-packs. Thus each U shaped clip can provide ground contact for two of

the ground electrodes (which cover 4 surfaces of the filter packs) if the ground electrodes 4 are in a V shape *i.e.,* they are continuous between two adjacent surfaces of the V-pack filter.

[0085] End caps 2a on the upstream side as shown by Fig. 1a are preferable made of a non-conductive material or plastic extrusion. In this case, CTE plates 5 can then be maintained securely within upstream plastic end caps 2a, and gap 6 shown in Figs. 1a, 6 and 8 is not then required. Thus, since the entire inside of the V-pack is potted with a non-conductive plastisol, the CTE plates 5 are essentially maintained in electrical isolation, provided however, care is taken to ensure that the CTE plates 5 do not contact the frame. It is, however, not essential that upstream end caps 2a be made of a non-conductive material. It is possible to use metal end caps as in the downstream end caps, provided that CTE plates 5 are not in electrical contact with elements of filter 31 that are at a different potential, and gap 6 is maintained with these metal end caps 2a shown by Fig. 1a and Fig. 6. Typically, a separation distance of about 0.25"-0.375", that is, gap 6, is maintained between CTE plates 5 and metal end caps 2a to ensure that there is no electrical discharge and proper isolation of CTE plates 5. This, then enables easy conversion of a manufacturing process that is already set up to manufacture conventional V-pack filter elements with metal end caps only.

[0086] The non-pleated filter medium 16, 17 may be incorporated into a non-pleated configuration suitable for use in lower efficiency filtration applications, although non-pleated filter media may be adapted to higher filtration applications also. The filter medium may be in a flat, continuous thick mat or felt form 16 as shown in Fig. 8, or in thin paper form 17 as shown in Fig. 9.

[0087] Fig. 17A shows one embodiment of the filter assembly 3 with filter medium 16, 17 bonded into the preferably non-electrically conductive frame of filter assembly 24 to form a potted filter element 186 via a plastisol or other adhesive as in the case of the V-pack filter described above, with filter medium 16, 17 maintained in direct contact via light bonding by means of an adhesive to downstream ground electrodes 4 which is in an electrically conductive, continuous, deeply pleated or corrugated and perforated form. CTE 5 may similarly be a continuous deeply pleated or corrugated and perforated, electrically conductive member that is then attached to the frame 24 such that it is in essential contact with the filter medium, or if the filter medium is very thin paper, depending on the electrical design, a small gap 18 of about 0.04" to 0.25" may be maintained between CTE 5 and the upstream surface of filter medium 17 in order to achieve charge stability without risk of spark discharge. Glue

beads 18 may be used on the CTE 5 to also ensure this separation distance between medium 17 and CTE 5. This embodiment is a throw-away filter and is deployed for high filtration efficiency applications. Downstream ground electrode 4 which is also a continuously deeply pleated or corrugated and perforated, electrically conductive member, is removable and is designed to fit into the pleated form of CTE 5, which is constructed as a discrete member, such that there is enough room for filter medium 17 in between CTE 5 and electrode 4 when the downstream ground electrode 4 is attached to the frame via a set of screws 41 or other fasteners such as clips.

[0088] Fig. 17B shows the non-pleated media 16, 17 embodiment 188 which enables a user to simply replace the filter media when it gets dirty with entrapped particles, rather than throwing away the entire filter assembly. Consequently this embodiment is usually not deployed for high filtration efficiency where high filtration efficiency is defined as applications for filtration providing greater than approximately 95% particle removal at sub-micron particle sizes. Non-conductive frame 24 which may be part of a filter housing or may be a separate component within such a housing, is used. CTE 5 is attached to this frame and is in a continuous deeply pleated or corrugated and perforated conductive form. Downstream ground electrode 4 which is also a continuously pleated and perforated, electrically conductive member, is removable and is designed to fit into the pleated form of CTE 5, which is constructed as a discrete member, such that there is enough room for filter medium 17 in between CTE 5 and electrode 4 when the downstream ground electrode 4 is attached to the frame via a set of screws 41 or other fasteners such as clips. Downstream ground electrode 4 has a flanged edge 39 which is sealed along with the filter medium against the edge flange of filter frame 24. The other perpendicular edges of the filter medium 16, 17 are relatively sealed to the frame by a layer of fiberglass or mat 40 or another material, that is able to prevent the passage of dust, that is glued to the top inner and bottom surfaces of filter frame 24. Alternatively, the system can be designed such that CTE 5 is removable and the downstream ground electrode 4 is fixed into the filter frame. Alternatively both the CTE 5 and ground electrode 4 may be removable. Other techniques may also be used to enable filter media replacement in the practice of this invention.

[0089] If a very thin filter medium 17 is to be used, then CTE 5 and downstream ground electrode 4 may be fitted with fastening points to the frame 24 so that there is there is space between the CTE 5 and electrode 4 for the media plus about 0.04"-0.25", depending on the

design of CTE 5 and the voltage applied to CTE 5. Typically the filter medium used is attached to the downstream ground electrode 4 or the CTE 5 member by means of either Velcro® strips attached to various points on the electrodes and on corresponding points on the filter medium or is simply pushed and maintained against the ground electrode 4 by the CTE 5 (or vice versa) or the members for creating the space described above, attached on the CTE 5. For improved contact to ground the filter medium 17 may have portions of it covered with conductive paint either by printing a pattern on it (similar to the printed CTE 5) or just along the edges of the folds. This conductive coating can assure better ground contact on the downstream side of the filter medium 17. Filter medium 17 is usually manufactured with folds or creases, which coincide with the pleats or corrugations or folds of downstream ground electrode 4 to facilitate attachment of the filter medium to downstream ground electrode 4 or CTE 5. To replace filter medium 17, the downstream ground electrodes 4 or CTE 5 is detached from the frame 24 and the dirty filter medium is replaced with a clean new folded medium.

[0090] Figure 15 is a blown up view of ionizer 30 and filter assembly 31 illustrating how ionizer 30 is used in conjunction with deep V-pack filter assembly 31. It should be noted however, that ionizer assembly 30 is mounted to or fits on to, by means of aligning channel guides, either of the above filter embodiments in the same manner in order to create a working electrically enhanced filter configuration. Hence, the ionizer 30 is also applicable to the non-pleated or folded filter embodiment.

[0091] The ionizer assembly 30 shown in the enlarged view in Fig. 7 is constructed with a perforated metal plate 7, with or without the pre-filter channel 25 or other mechanism used to hold a prefilter 45 at the upstream face of the ionizer. Onto this plate 7 high voltage electrodes 8, typically made of Tungsten are mounted at a separation of distance d_1 from the perforated metal plate. Electrodes 8 are mounted as single wires or in pairs or sets of wires, spaced between about 0.75" to 2" apart, depending on the opening within each of the V-packs or flat filter folds, onto a bus bar 10 which is in turn is mounted on top of dielectric and non-electrically conductive standoff or standoffs 13 made of non-electrically conducting material such as a ceramic. Stand-offs 13 typically are threaded on the inside at both ends so as to enable mounting via screws 12 on to a small non perforated section of the generally perforated metal plate (control ground electrode) 7 on one end, and the conductive metal bus bar 10 on the other end of each standoff 13. Wire electrodes 8 are then attached typically via springs

9 to holes 15 by using loops on the spring, to bus bars 10 and extended towards a similar opposing bus bar and spring assembly across the control ground electrode 7, so that the wires can be installed typically within the V opening. Alternately the bus bar may have one or more needle or sharp points on it to serve as ionization points. High voltage is applied to bus bar 10 and thence to electrodes 8 via high voltage cable 11 which is typically connected to a high DC voltage power supply via quick connect high voltage couplers. In order to eliminate any potential arcing from any rough metal surface of the ionizer's 30 bus bar 10, springs 9 or wire or spring loops, a dielectric non-electrically conductive C-shaped, channel shield 14 may be used to shield these components from other surfaces as shown in the enlargement of Fig. 6 presented by Fig. 7. Alternatively, instead of a C-channel, a flat dielectric plate covering the top of the entirety bus bar 10 and spring assembly may be used. Typically, non-electrically conducting materials such as acrylic or appropriate nylon or polycarbonate, which have appropriate dielectric properties, may be used to form shield 14.

[0092] Referring now to Fig. 15 and Fig. 19, ionizer assembly 30 may be attached to filter assembly 31 using fasteners such as threaded bolts or screws 23 which fit into metal guide tabs 21 attached to the exterior of filter housing 24. A wing nut 22 or other removably receptive fastener may be used to secure bolts 23. Tabs 21 enable one or sets or pairs of ionizer electrodes 8 to be correctly spaced within each V-shaped pair of pleats of filter assembly 31, while maintaining correct values of d_2 (cf Table II). The maintenance of proper values of d_2 for each of ionizing electrodes 8 and charge transfer electrodes 5 is important to assure the safe and efficient operation of the deep electrically enhanced filter. Alternatively, the ionizer assembly 30 may be constructed with angle guides so that it can be pushed against filter assembly 31 only in one way so as to maintain the above gap d_2 between the wires 8 and the CTE 5. The ionizer assembly 30 and the filter 31 are held and maintained in this position by means of bolts or other means that push both assemblies against the seal plate 34, such that the gasket 26 on filter assembly 31 is compressed against the seal plate 34.

[0093] Fig. 18 shows a housing that can be used to mount single or multiples of such filters and ionizers in air handling units 38. A filter frame assembly 32, which is sealed against a seal plate 34 in air handling unit 38 either by welding or other means such as by using polymeric seal materials. Frame assembly 32 has at least four members 29 mounted on at least 2 opposite sides; members 29 are installed into brackets with holes onto which a L-shaped rods or members 29 with threaded bolt on the end are inserted. At the threaded end

is a L-shaped washer with a nut that threads on to the L-shaped rod. This and other such filter sealing assemblies are available from companies such as Camfil-Farr and AirGaurd among many others, and hence this mechanism need not be drawn in detail or described further here.

[0094] Filter assembly 31 and ionizer assembly 30 are first assembled together and then inserted into frame 32, as an united assembly, and then the nuts and L washers or clips on sealing member 29 are tightened to be pulled over the edge of ionizer control electrode 7, which pulls the entire assembly together, thereby compressing gasket 26 against sealing surface 34.

[0095] In the assembly shown by Fig. 18, it is not possible to use metal guide tabs 21, as shown in Fig. 15, because there is typically no room for guide tabs 21 on the side of filter frame assembly 32. In this case, ionizer assembly 30 is accurately guided into filter assembly 31 by a set of two or four channel guide members 33 attached to the ionizer assembly 31. Guides 33 fit snugly over the filter assembly thus properly positioning the ionizer assembly 30 within the filter assembly 31. Sealing member 29 then holds assemblies 30 and 31 together.

[0096] Figs. 18 and 19 show housing 38 along with the connections of air inlet 42 and outlet duct 43. Housing 38 may contain a fan 35, cooling and heating coils (not shown) and the filtration system of ionizer 30 and filter assembly 31. Fig. 19 also shows electrical box 44, which is mounted on the outside of air handler housing 38. This box contains the high voltage power supplies, indicator lights, switches and controls that enable control the filtration system. Housing 38 also has a service door, which is typically a walk-in or side access door to change the multiple number of filters. For single filters, the service door is located so that the filter seal member 29 and the threaded fasteners are easily accessible from the outside.

[0097] Fig. 19 shows an isometric view of a typical housing 44 that is separate from the air handling housing 38, that can be used within a duct system that is connected to air handling unit housing 38. The typical housing 44, often referred to as an in-duct filter housing, uses of an optional fan 35 to draw the air through the enhanced filter system, electrical component compartment 37, seal plate 34 and service door 36. The controls and indicators 46, are mounted on the outer surface of electrical compartment 37. A grounding clip 47 of an electrically conducting material such as metal, or with the alternative self-fastening structure of clip 47' bearing deformable retainers 47a shown in Fig. 19A, forms an electrical path of conduction between downstream ground electrode 4 via end cap 2, and the electrically

conducting frame of filter assembly 31. The frame of filter assembly 31 serves as a local reference potential such as ground, and may be electrically coupled to a ground potential, such as earth, with a grounding strap (not shown). Optionally if the filter frame is non-conductive a separate ground clip, typically with multiple U members that straddle each apex of the V-pack to make ground contact with each set of ground electrodes 4, may be used. In this case the ground clip is designed to fit on to the filter V-pack apexes in a manner that it also makes contact with the filter housing. Ionizer 30 and filter 31 assemblies are also shown without detail. Either filter assembly 31a or 31b, or another filter assembly, may be used as filter assembly 31. It should be noted that the ionizer control electrode 7 may be formed in a manner such that two U-shaped channels are formed which enable a prefilter to slide into the U-shaped channels. This serves as a convenient prefilter holding assembly. This simple configuration is not shown in detail here. Alternatively, a conventional prefilter frame that attaches to a conventional filter frame may be used as described above for the case of the air handling unit application. If fan 35 is not required in the construction of a particular embodiment, a flow switch or contact provided form an air handler fan may be used so that when there is no airflow, then the high voltage power supply to the ionizer wires is shut down. Service door 36 is positioned so that when door 36 is open, a safety disconnect switch is opened so that all power to the filter unit is disconnected.

[0098] Either the upstream side or the downstream side of the filter depending on which side the filter is sealed against seal plate 34, has a polymeric (typically closed cell polyurethane foam or rubber) gasket 26 with sufficient hardness for sealing assembly 31 against seal plate 34. Filter assembly 31 is then sealed against seal plate 34 by either applying external force against ionizer assembly 30 by incorporating a bracket 48, which is threaded to move a bolt 49 with knob attached as is shown by Fig. 19, or by tightening nuts or wing nuts 22 onto bolts that are attached to the seal plate. Alternately, the bolts may be moved through nuts mounted on the intake side of the filter housing (around the fan) so as to move against the ionizer-filter assembly. These bolts can also go through the metal guide tabs 21 that are welded on to filter assembly 30. Alternatively, placement of sealing member 29 onto filter frame 32, enables attachment of springs that pull filter assembly 31 onto the seal plate as shown by Fig. 18. Only the bolt 49 sealing configuration is shown in Fig. 19. Filter assembly 31 can also be sealed against seal plate 34 by a variety of other common and conventional sealing mechanisms, such as adding a knife edge to filter assembly 31 or seal plate 34, which seals

up against a gel embedded all around seal plate 34 or filter assembly 31. The sealing mechanism is not shown in detail in Fig. 19.

[0099] Fig. 20 illustrates the construction of an alternative embodiment with at least one of the pockets in the filter assembly 31 formed by a pair of folds 52 line in substantially, approximate parallel planes joined at the downstream, closed and by a curved, or C-shaped, apex 50, rather than a V-shaped apex. The ionizing assembly 30 may be constructed with a single electrode 8, rather than an array formed by a plurality of electrodes 8, spaced approximately equidistantly between the upstream surfaces of CTE 5 of each pleat 52. Insulated spacers 18, or glued beads, may be used to electrically separate CTE 5 from the unfolded, thinner medium 17 if necessary for collection filed stabilization.

[0100] Fig. 21 illustrates the construction of an alternative embodiment with potentially intersecting arms 54 joined at a curve, or C-shaped apex 50. Ionizing assembly 30 may be constructed with multiples of either a single or a pair depending on the opening of the filter folds, of ionizing electrodes 8, each separated by a least distance d_2 from the closest surface of CTE 5.

[0101] The foregoing paragraphs describe the details of a method and apparatus that uses deep filters as an efficient and safe electrically enhanced filter (EEF) in order to obtain ultra low pressure drop, high efficiency of particulate removal and high dirt holding capacity and life of the filter. The EEF is constructed with a housing (with or without an internal air moving device such as a fan), and a deeply pleated filter preferably a V-pack filter with sets of downstream ground electrodes 4 and charge transfer electrodes 5 borne by the opposite, major parallel outer surfaces of filter medium 1, 16, 17 assembled in a filter pack within as a unified filter element. Seal plate 34 seals against the gasket on the filter element to prevent blow-by of air; ionizer assembly 30 ionizes the gas and charges particles entering between the deep pleats of the filter element and also transfers a charge to the charge transfer electrodes 5 on the filter pack. A high electrical potential is applied to electrodes 8 or other charging elements in the ionizer. Charge transfer electrodes 5 enable the device to function with a high particle collection field between charge transfer electrodes 5 and downstream grounded electrodes 4 that enables higher entrapment of the particles on the deep filter medium, in a safe and efficient manner. In effect, the use of the charge transfer electrodes (CTEs) 5 allow the deeply pleated filter to function as an effective filter while avoiding the inherent inability of contemporary designs for filters to accommodate a greater depth of the filter element.

[0102] Ionizer assembly 30 has a ground control electrode 7 and high voltage electrodes 8 with appropriate shielding. This configuration stabilizes the corona and minimizes the possibility of field cancellation or back corona discharge as a result of coating of counter electrode 7 with highly resistive dust. The high field strength between ground control electrode 7 and the high voltage applied to electrodes 8 results in corona charging of incoming airborne particles. In the practice of this invention, the distances between the ground control electrode 7 and electrodes 8, and the spacing between electrodes and the CTEs 5 determine the surface potential developed on CTE 5 and hence the collection field between CTEs 5 and the downstream ground electrodes 4. In alternative embodiments, control ground electrode (CGE) 7 and downstream ground electrode (DGE) 4 may be at either a negative or at a lower potential with respect to the applied potential, and do not need to be rather strictly at ground potential.

[0103] Additionally, although contemporary devices accumulate dust in patterns that can sometimes generate undesired back corona discharge, embodiments constructed according to the principles of the present invention require that the dust would have to travel against the direction of the air flow in order to accumulate on ground plate 7; this minimizes the risk of back corona discharge that has plagued contemporary filters due to accumulations of dust.

[0104] In the typical practice of my inventions, referring, by way of example, to the embodiment illustrated by Fig. 6, filter medium 16 may be pleated into a plurality of successive pleats, with a pleat depth being between approximately 0.25" to approximately 6" inches in depth. Charge transfer electrode 5 may rest upon these pleats, and the shortest distance, d_2 between CTE 5 and the closest one of ionizing electrodes 8, is on the order of between approximately 0.25" to approximately 2". Ground control electrode 7 should be spaced-apart from ionizing electrodes 8 by approximately 0.25" to approximately 1.5". The voltage applied to ionizing electrodes 8 is between approximately 3 to approximately 18 kilo-Volts.

[0105] Although several of the embodiments are illustrated with ionizing electrodes 8 in the form of straight, electrically conducting wires, other embodiments may be constructed with sharp, distally extending objects such as needles or points.

[0106] The foregoing discussion describes the details of a method and apparatus using deeply pleated filters to provide efficient and safe electrically enhanced filtering (EEF), with ultra low pressure drop, higher efficiency of particulate removal and higher dirt holding

capacity over the life of the filter. An EEF may be constructed with a housing, with or without an internal air moving device such as a fan, a deeply pleated filter, preferably a V-pack filter with sets of downstream ground electrodes and charge transfer electrodes borne by the exterior surface of the filter packs that form the filtering element. An ionizer assembly that ionizes the gas and charges particles entering the deeply pleated filter and also transfers a charge to the charge transfer electrodes on the filter pack. A plate seals against the gasket on the filtering element. A high electrical potential is applied to charging elements in the ionizer. The charge transfer electrodes enable the device to function with a high particle collection field between the charge transfer electrodes and the downstream grounded electrodes, irrespective of filter depth, to safely and efficiently attain higher entrapment of the particles on the filter medium.

[0107] As described in the foregoing description, the details of an electrically enhanced filtering apparatus, and a process for constructing that apparatus, contemplate a layer of a porous filter medium exhibiting a thickness, folded into arms forming one or more pockets with an apex of the pocket located on a downstream side of the medium and with a base of the pocket open to an upstream side of the apparatus. A first electrically conducting, perforated grid may be disposed over a first major exterior of the medium to cover the downstream side of each of the arms, a second electrically conducting, perforated grid electrically separated from the first grid by the thickness of the medium, may be disposed across a second major exterior of each of the arms on an upstream side of the medium, and a control electrode, which may be maintained at a local reference potential such as ground, is spaced-apart upstream from the second electrically conducting grid. An ionizing electrode may be interposed between and separated from the control electrode and the second electrically conducting grid, on the upstream side of the medium, with the ionizing electrode spaced-apart from opposite corresponding arms of the medium while extending along the length of the pocket, parallel to and spaced-apart from the second grid.

[0108] A typical conventional V-pack filter with this pleated V pack construction could exhibit a filter efficiency of 99.99% with a particle size of 0.3 micrometers, and provide a pressure drop of about one inch water column at a filter face flow velocity of 600 feet per minute. Another conventional grade of a V-pack filter with a filtration efficiency of 95% at 0.3 micrometers particle size, and has a pressure drop of about one-half of an inch water column (*i.e.*, 0.5" WC) at a filter face air flow velocity of 600 feet per minute. I have found

that if such a 95% filter could be enhanced in a safe electrical manner to provide approximately 99.97 to 99.99% filtration efficiency at 0.3 micrometer particle size (commonly referred to as HEPA filtration efficiency), then an ultra low pressure drop HEPA filter could be achieved with significant savings in operational costs than are available with conventional HEPA filters. Similarly, lower grade, deep V-pack or other forms of deep filter material could be safely electrically enhanced to produce higher efficiency filters having significantly lower pressure drops. The operating cost savings would be in terms of fan power required and the longevity of the filter, improvements that result in savings in terms of energy, downtime, labor and material costs related to filter replacement and maintenance. The consequential benefits in industrial applications (cf. Jaisinghani, "*Energy Efficient Cleanroom Design*", 2000) could be as high as 60% savings in energy consumption related to air moving. Currently, commercial buildings in the U.S. annually consume about 0.75 quads of energy attributed to the cost of moving air. If other industrial applications are included, the electrical energy consumed by fans in heating, ventilating and air conditioning applications are probably about twice this number. Embodiments of this invention would provide a significant reduction in the overall industrial energy consumption required for air moving and heating, ventilating and air conditioning (*i.e.*, HVAC) costs, this provides significant reductions in greenhouse gases and other pollutants associated with energy production. The estimated annual U.S. potential for savings in atmospheric carbon is about 9.7154×10^6 metric tons of carbon.